

10-17 July 2019 - Ghent, Belgium

Community challenges and opportunities for detector R&D

Outcome from the European Particle Physics Strategy Open Symposium in Granada

A.Cattai –CERN–



Inputs & disclaimer

- Documents submitted by the communities for the European Particle Physics Strategy Update <https://indico.cern.ch/event/765096/contributions/>
- Talks and round table discussion @ R&D session in Granada
- Results from 2 surveys → status of R&D in Europe *by the ECFA detector panel representing ~2900 FTE*
→ recognition of individual achievements
by ECFA 1355 participants
- Discussions & inputs from Colleagues and ECFA Detector Panel

..... **but selection of topics & critical views are my own**

with apologies to all interesting R&Ds not covered

160 submissions gave an overview of the different researches in different environments

Dealing with detectors:

14 submissions

Future colliders (*CLIC, FCC, ILC, μ Coll....*)

7 submissions

“*The invisible*” elusive particles

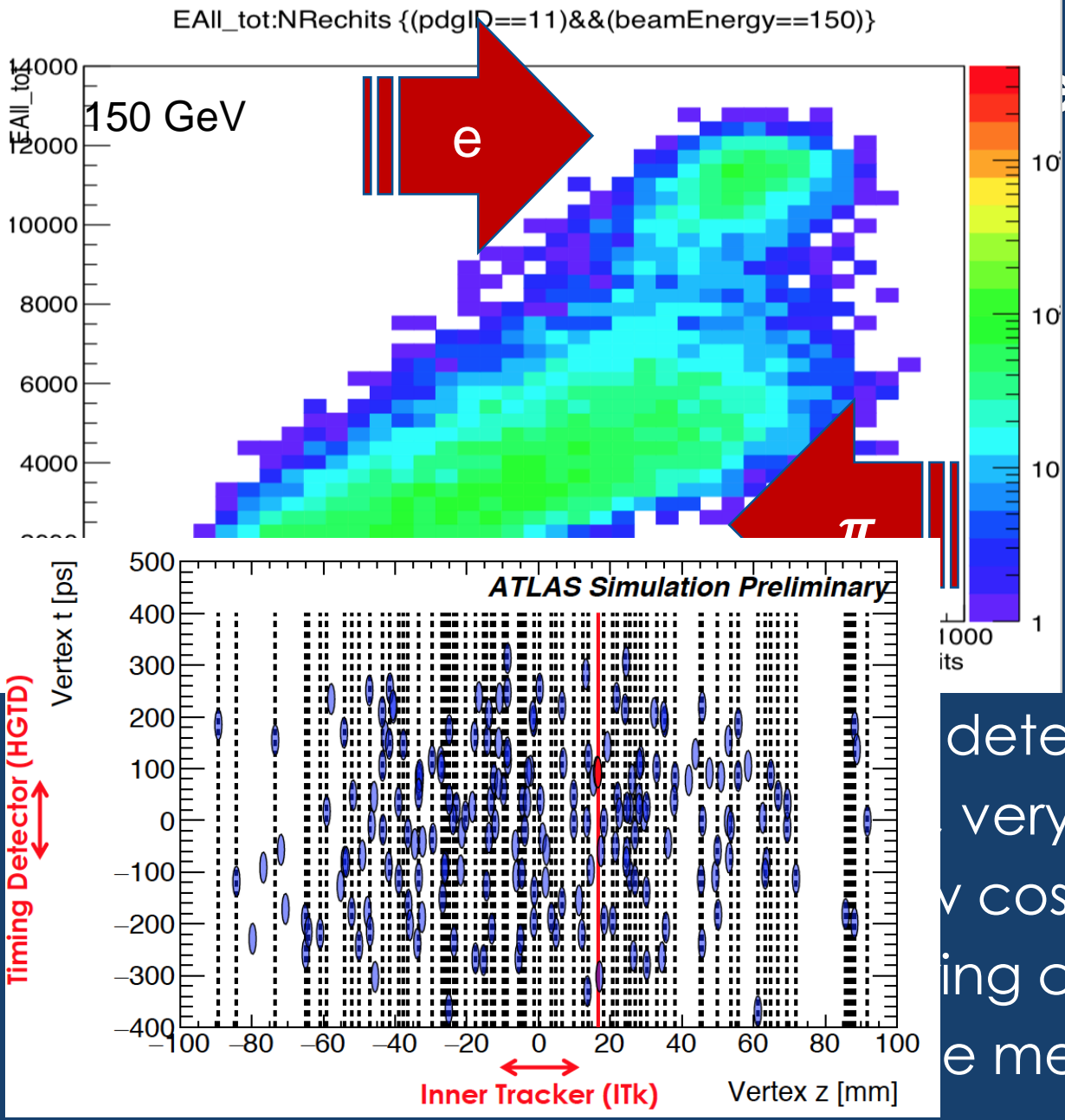
- * Neutrinos near and far detector - Reactor neutrinos
- * Low energy high sensitivity ($0\nu 2\beta$, $g-2$, EDM, ...)

7 submissions

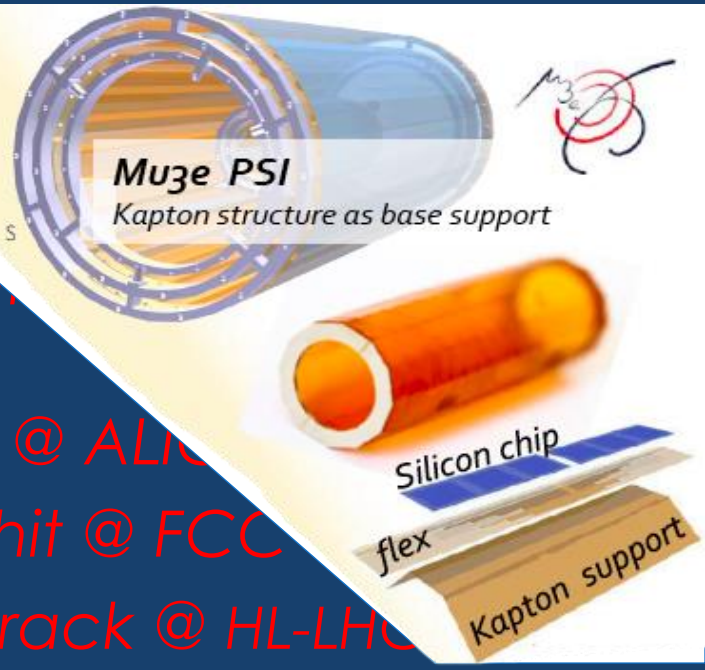
Astro-particle and cosmology

- * Dark matter detectors
- * Cosmic rays - Gravitational waves- Satellite experiments

Very different requirements from many fundamental detector technologies



experiment



- $10 \times 10 \mu\text{m}^2$ @ ALICE
- ~ 10 ps per hit @ FCC
- ~ 30 ps per track @ HL-LHC
- $\sim 0.05\%$ X_0 per layer @ ALICE++
- $10^{17-18} n_{eq}/\text{cm}^2$ @ FCC

detector (5D imaging)
 very high readout speed
 low cost

} image
 calorimetry
 PFA
 Rad Hard LiAr

engineering challenges: powering, extreme
 mechanicals and production techniques

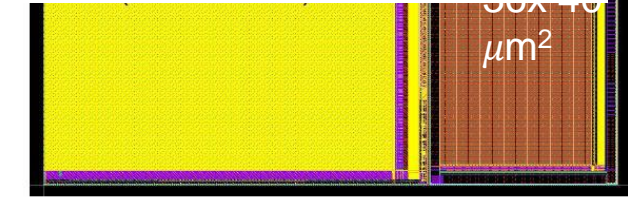
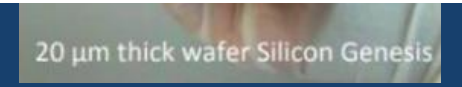
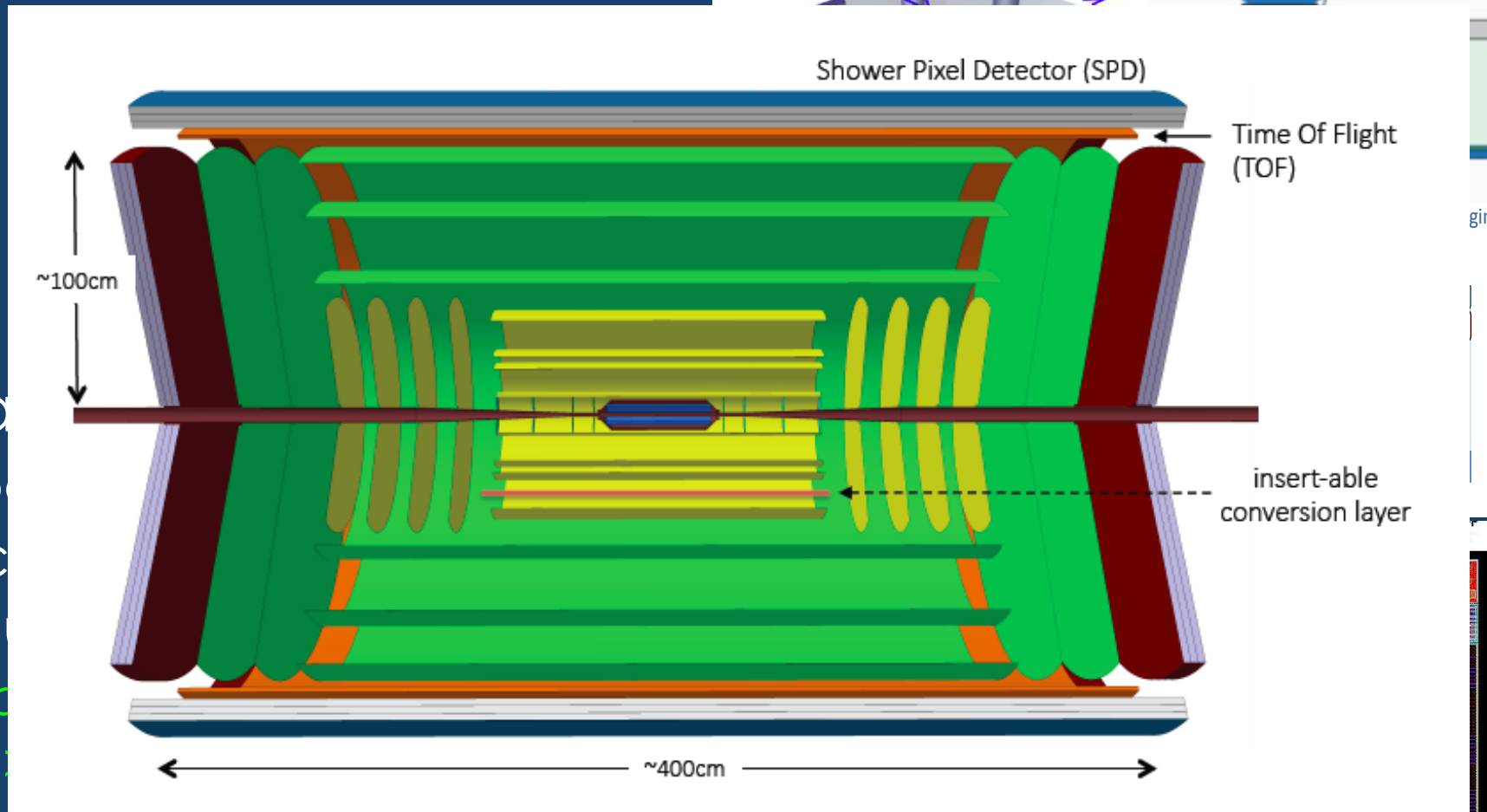
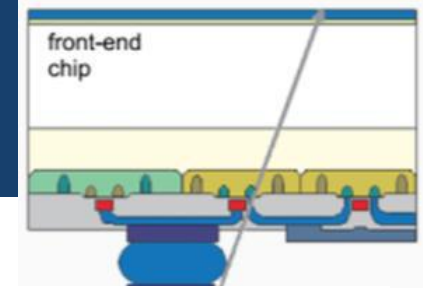
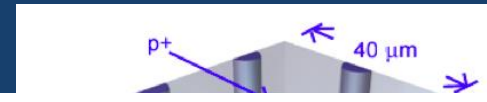
	Solid state Vertex	Solid state Trackers	Gaseous Trackers	Scintillating fibre tracking & calorimetry	Calorimetry	Particle Identification
Challenges	3D, (HV-)CMOS, MAPS, FPCCD, LGAD μ -electronics @ 65nm-28nm	HV-CMOS, Sol, (D)MAPS, LYSO tiles+SIPM, LGAD timing layers	GEM, MM, THGEM, μ -RWELL, μ -PIC, GEMpix, TPC, Drift Chambers, sTGC, RPC	NOL Nano-Organo-Si- Luminophores, Crystal fibers	à la CALICE Si/W, MAPS, LiAr,LYSO, Dual RO, Shower Pixel Detector, Metamaterial	RICHs, TORCH,ToF, ToP
Granularity --> space resolution	100x150 μ m - ALPIDE:27 μ m*29 μ m Hybrid: 50x50 μ m - CLIC&CLD:25*25 μ m ALICE++ μ SiPM 10*	CLIC: 1 mm track for 50	>100 μ m ILC: 100 μ m in r ~ 1 mm in z 50 μ m ->10 μ m ILD: TimePix with 5 μ mX55 μ m	LHCb SciFi: 80 μ m, PEBS:55 μ m ATLAS alpha~25 μ m SPACAL:1x1 or 2x2 cm2	ECAL 5*5mm**2 HCAL 3*3 cm**2 for PFA with CALICE HL-LHC: 0.5 or 1cm2 Challenge for LiAr 5x20mm2	LHCb single- γ 0.7 mrad LHCb: single- γ 0.2 mrad
Fast & precise timing		ILC 300 ns-ms Timing Layer: LGAD ~30ps/track	~10nsec 25 ps@PICOSEC	Mu3e: 0.5 - 1ns SPACAL: 20-40ps	25 ps timing 5D calorimetry HL-LCH, μ Coll: Timing Layer: Lyso+SIPM ~30ps/track	LHCb & TauFV RICH:10ps - TORCH:10-15ps/track ALICE++ ToF: CMOS MAPS or LGAD with time res. ~ 20 ps
Rate capability	100--> 4000 MHz/cm2	FCC-hh: pile-up/bunch Xing O(1000)	2.5 MHz/cm2 μ -RWELL 10MHz/cm2	40 MHz SPACAL: up 3MHz/cm2	FCC-hh 8 charged particles per rapidity unit.	
Rad Hard of detectors & electronics, cables.....	10 ¹⁵ neq/cm2 - 3D hyb: 10 ¹⁶ neq/cm2 FCC-hh:10 ¹⁷⁻¹⁸ neq/cm2 & 220 Mgy	10 ¹⁵ neq/cm2 - 10 ¹⁷ neq/cm2 timing layer 2x10 ¹⁴⁻¹⁵ neq/cm2	10 ¹⁶ neq/cm2 1.6 C/cm2	NOL:~10 ¹³ neq/cm2 @- 14C ~10 ¹⁴ neq/cm2 kGy- >10kGy SiPMS10 ¹² neq/cm2 @-4C SPACAL:~1MGy & 6-10 ¹⁵ neq/cm2 at 300 fb-1	CLIC~ 20 Mrad/ year in the FWD FCC-hh: 2x10 ¹⁶ neq/cm2 in EndCap LiAr	~50 kGy
Low material budget	ALICE: 0.35% CLIC: 0.2% CLD:0.3% ALICE++0.05% X0	~2% X0 per layer	CEPC IDEA: Drift chamber: 1.5% X0 & 3%X0 before the pre- shower	1% X0 /layer (complete module) 0.25% (fibre only)		thinner radiators
System integration	mechanics, truly cylindrical sensor, cooling, power, cables	mechanics, cooling, power, cables	eco-gas, optical read-out	mechanics, cooling, power, cables	mechanics, large area, cooling, power, cables	light carbon-fibre based mirrors - cooling for SiPM - operation in B field, photodet.

40% FTE

- Enormous effort in many directions (40% FTEs are involved in R&D on solid state detectors for vertexing and tracking)

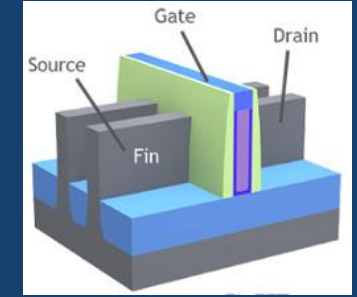
- Planar ?
- 3D ?
- Hybrid ?
- Monolithic ?

- CMOS MAPS most of
 - Can be thinned to b
 - Can be stitched to c
 - Inherently high gran
 - MALTA $\rightarrow 10^{15} n_{eq}/cm^2$ of hit-rate capabilities of

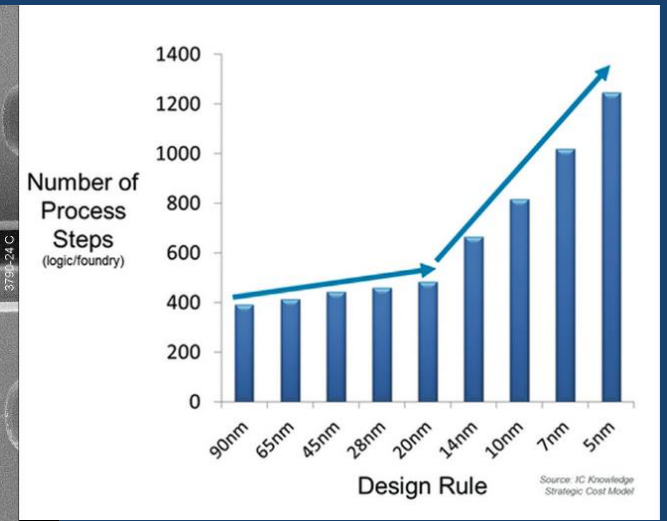
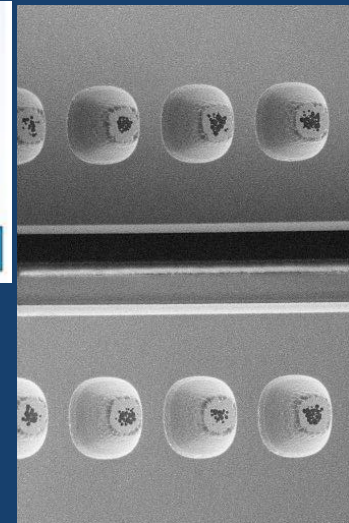
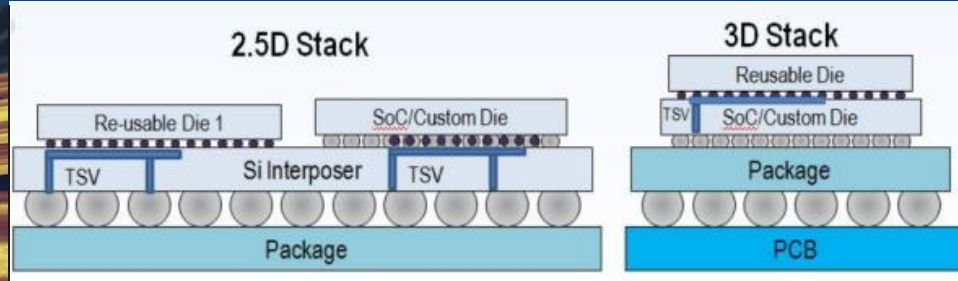
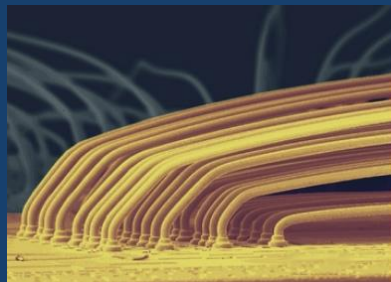


The real challenge: RO electronics !!!!!

- Crucial role in all systems
- Technical challenges *and more.....*:
 - If down to pitches $< 20 \mu\text{m}$, high density, rad hard, fast $\sim 10 \text{ ps}$
 - You need to use electronics in 28 nm node or less
 - Exploits 3D VI geometries **NEW** to our community

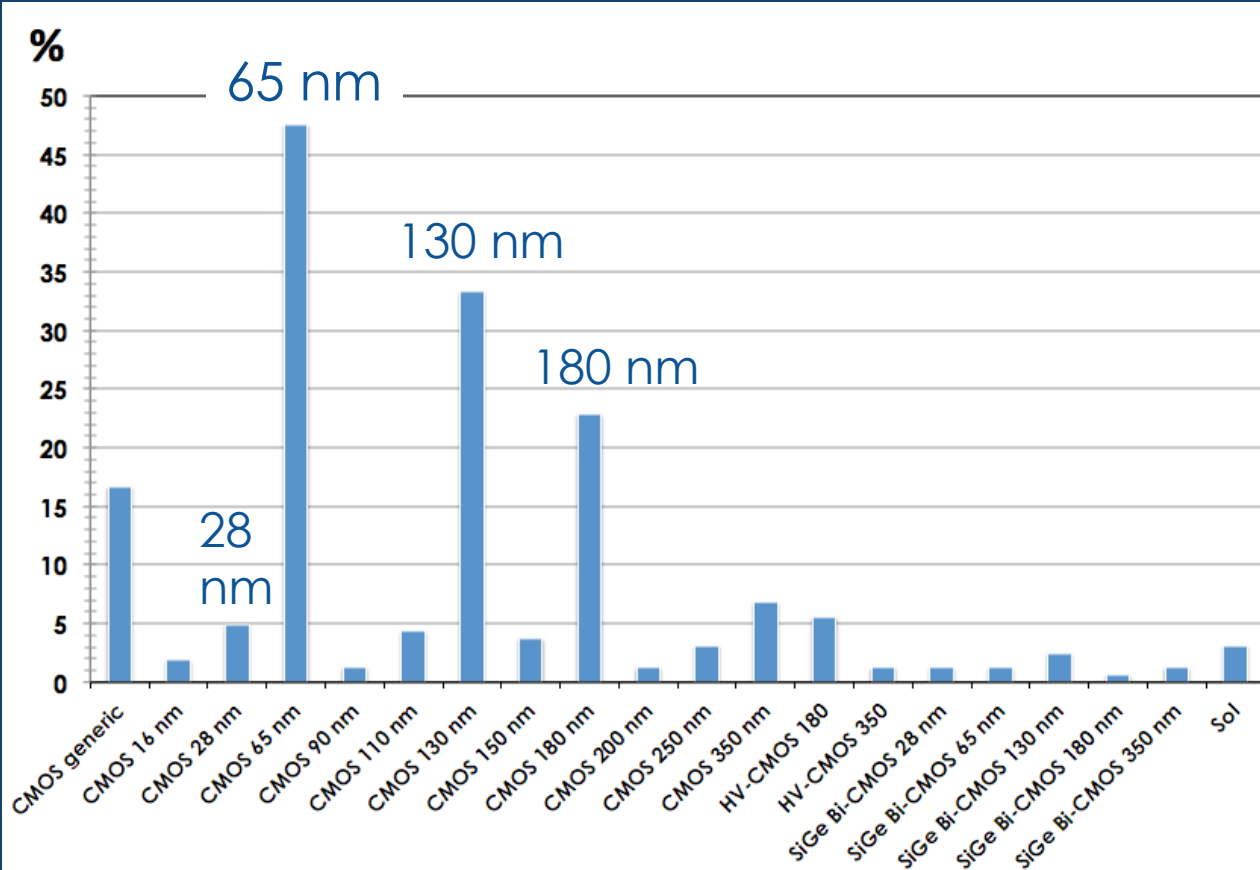


FinFet @ 14,10,7 nm

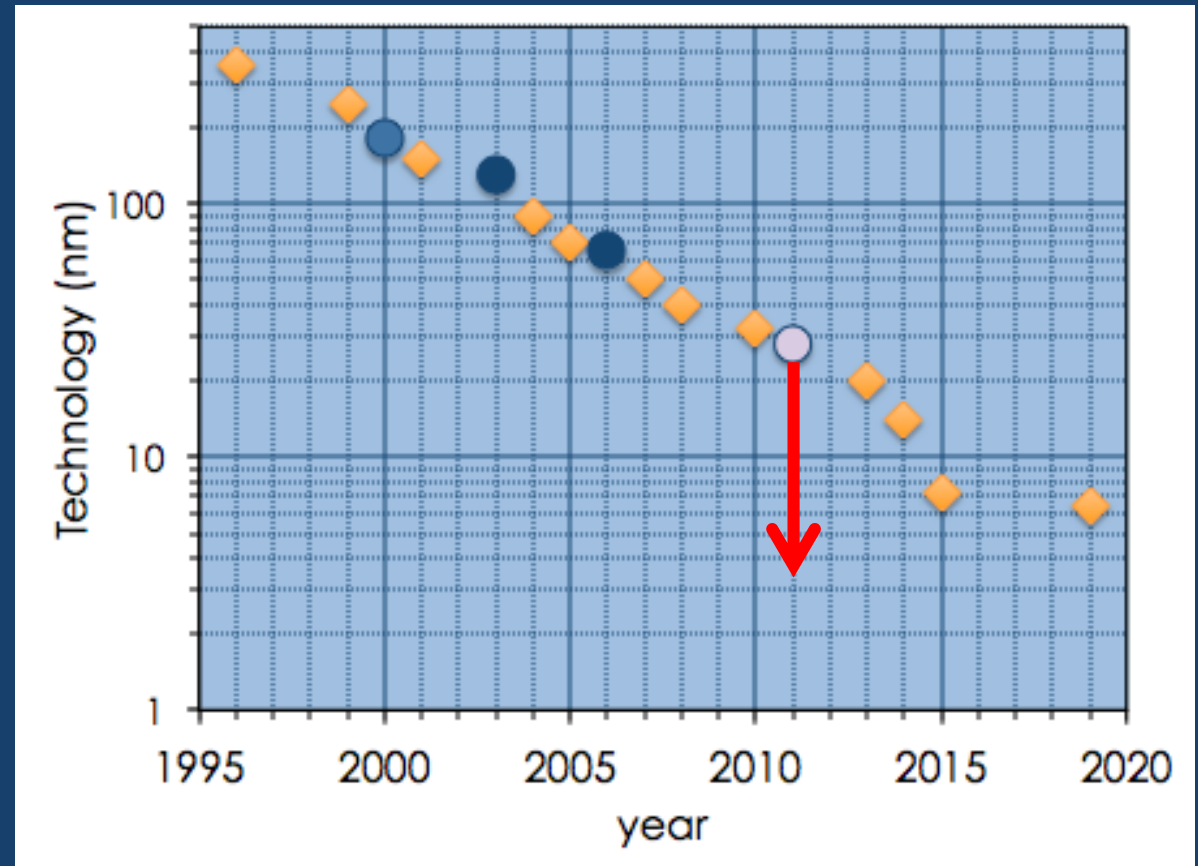


- Complexity of the design increases
- Industry-driven technology

Involvement of FTEs in μ -electronics



Technologies exploited by industry



The μ -electronic real challenges

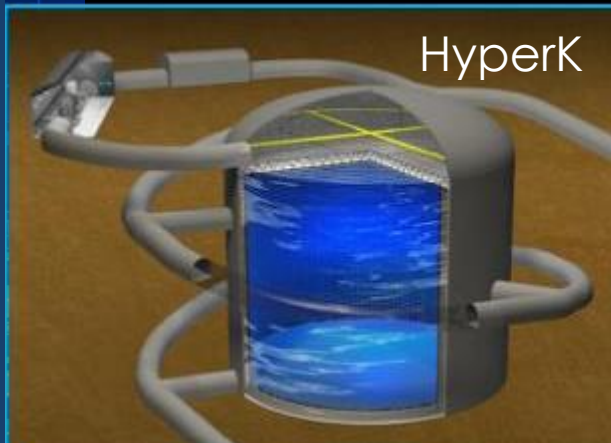
- Many years behind industry
 - we risk to become obsolete
- The cost of the engineering runs are outrageous !!!!!
 - We can afford to invest only on a limited amount of technologies
 - which one ????? strategic choice !
- We are small clients (see D. Contardo talk @Granada)
 - Cross-experiments collaboration mandatory
 - Expensive tools and corresponding user support must be set up in a central way for the entire community
 - Common submissions to foundries need to be organised through central frame contracts
 - Urgency of international coordination & adequate resources for shared programs

ν , Dark Matter and known unknowns

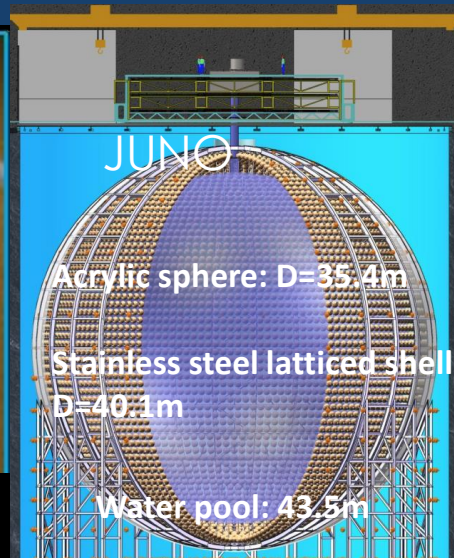
Demand for stronger CERN engagement in astroparticle Physics

Challenges & synergy with accelerator Physics

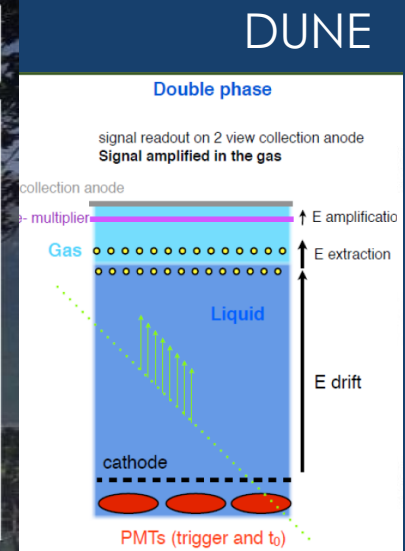
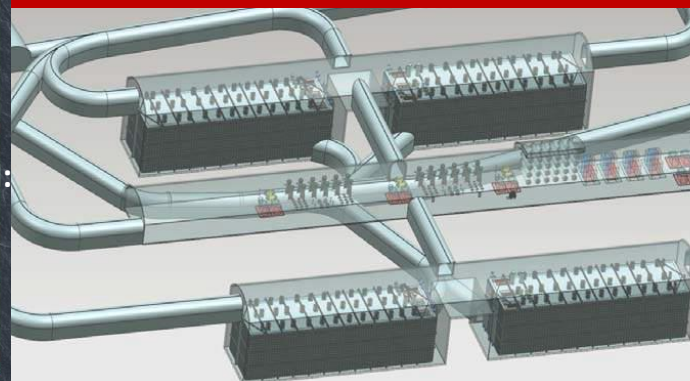
- “Radio purity”, huge mass, active shielding, large cryogenic infrastructure
- Dual phase operation
- Huge number photo detectors → many progresses SiPM & LAPPD



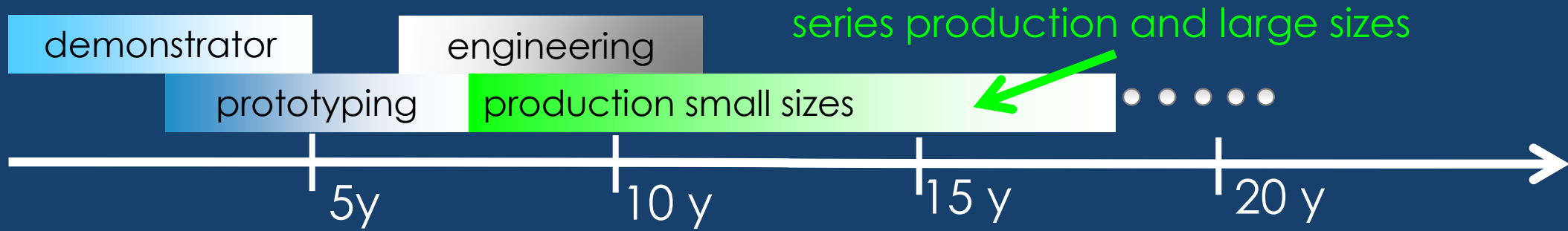
- 260 kton ultrapure water
- 190 kton fiducial mass: 10×SK



40 kton Liquid Argon Time Projection Chamber (LArTPC)



- Complex technologies have long (*and costly*) R&Ds

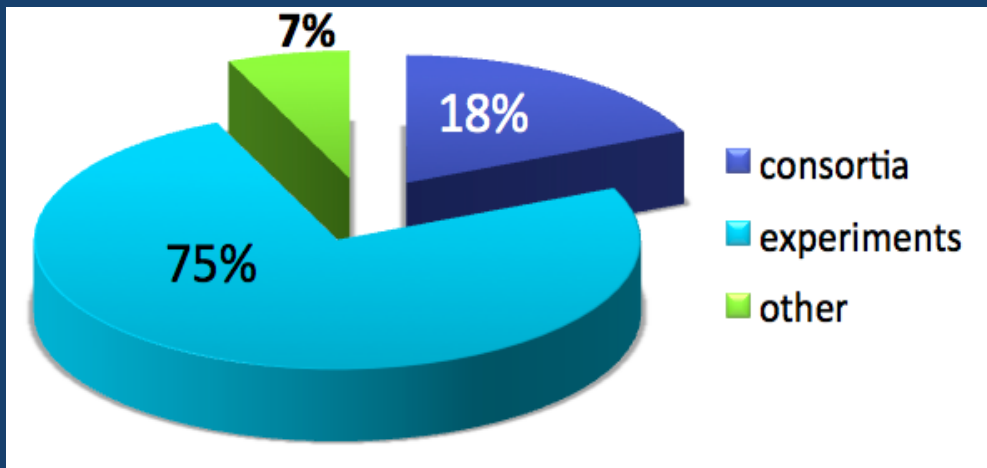


- Experiments that last a lifetime with thousands of people
→ Carry along a palette of ineluctable challenges

Discussions in Granada were organized around 3 major R&D themes

- **Coordination of R&D** Distributed everywhere in independent way ?
Centralized in laboratories and consortia ??
- **Human factor** How to give recognition to young people? Foster recruitment ?
How to be effective with long term training ?
- **Technical⁺⁺** R&D guided by existing experiment ?? Blue sky R&D ??

Blue sky R&D?



- large majority → R&D driven by well defined requirements of experiments
- minority → consortia (AIDA.....)
- very small minority → driven by what **today** is impossible but **tomorrow will be the new ??????**

Maybe linked to the funding scheme ?

Funding agencies	% of respondents
International funding program	13
EU funding program	32
National funding agency	71
Home Institute	52
Other (Mainly private or industry)	1

a touch of history.....

TPC

Nygren 1974 "..... it was a question of aesthetic

RICH

Seguinot, Ypsilantis, Ekelof 1977

Si strip

many....1970-80

RPC

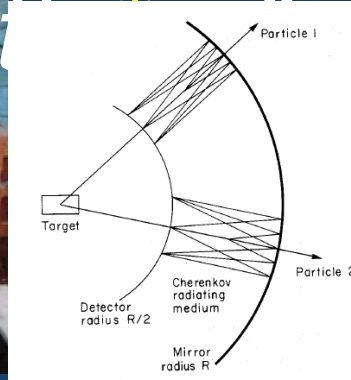
Santonico, Cardarelli 1981

MPGD

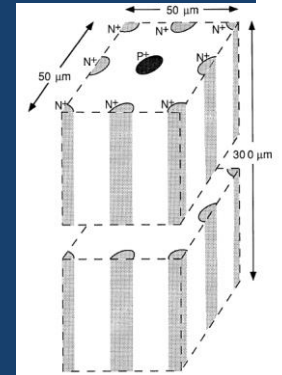
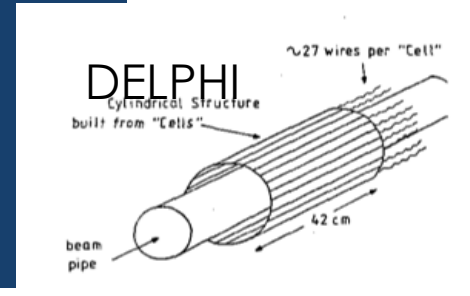
Charpak, Giomataris, Sauli ~1995

3D Si pillars

Parker, Da Via' 1997



Blue sky R&D pays



Coordination of R&D activities

Obvious evidence → Expertise is distributed in many institutions

General opinion → R&D should not be centralized **exclusively** in large-scale facilities and/or in major labs



that remain key places for exchanges of ideas and their unique technical support



	YES (%)	NO(%)
Need to be coordinated among Physics communities	77	23
Need to be better and/or more centrally organized	50	50

Coordination of R&D activities

- Extend working relationships
 - Organize "exchange of idea" platforms with a multidisciplinary approach, sources of new technologies, industry
- Current R&Ds collaborations (eg. RD#, AIDA2020, CALICE, etc.) are effective models of collaboration *(Develop, provide access & distribute common tools*
 - *Most effective framework to share resources with small institutes/users)*
 - Strength and establish new ones
 - Need to optimise the reviewing process and implement regular reassessments in addition to the collaboration internal procedures
- Reflect on how to support and strength the community doing R&D suited for application outside HEP

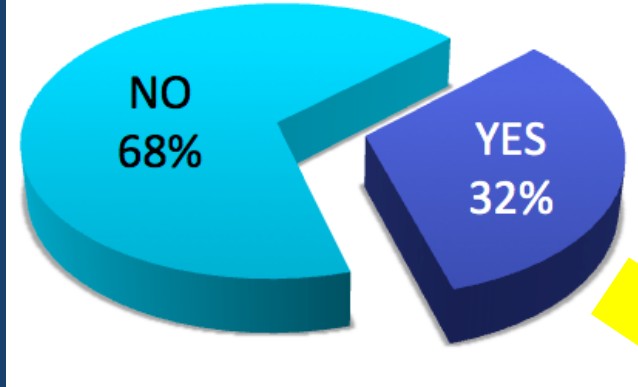
~80% of respondents perceive that their R&Ds are suited for applications outside fundamental physics

	% of respondents
Dosimetry	26
Civil security	18
Cultural heritage	10
Medical	65 %
Nuclear control	25
Other **	18 %
	>> 100 %



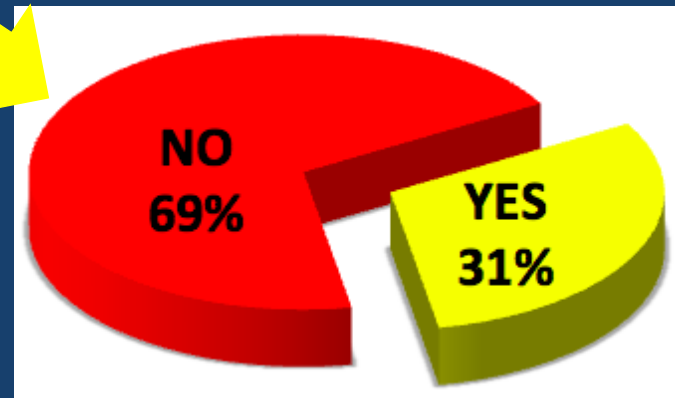
** Photon science, geophysics, volcanology, industry, magnets related, muon & large tomography, data handling, space, agriculture, optics, precision metrology, marine biology, environmental, high-tech engineering, telecommunications,....

Only ~30% of the projects engage in technology transfer programmes



The majority of them have not enough support to solve:

- financial problems
- manpower
- technical
- legal problems



→ Reflect on how to obtain adequate effectiveness in the process of technology transfer from detector R&D to society applications

Human factor

Perceived perspective for job/career opportunities for detector experts

	YES (%)	NO (%)
In research field	39	61
In industry	66	34
In tertiary sector, requiring advanced software development skills	80	20

Expertise acquired by young researchers @ labs/institutes is GREAT !!!!!

BUT our current career model, to keep the researchers in house, doesn't work very well !!!

R&D activities are not considered as rewarding as physics analysis and they do not grant equal career opportunities

The success and future of our field depend on our ability and strength:

- to attract the most talented researchers
- to recognize individual achievements especially within large collaborations
- to provide adequate career opportunities

→ Instrumentation activities must be recognized as a fundamental research

→ Career opportunities for detector experts must be greatly strengthened

F. FORTI → at recruiting time need to change the attitude: “this person only knows about detectors, should we really hire him/her ?”

Education & training

- PhD/postdocs often lack basic knowledge because University courses are often insufficiently oriented towards technical aspects

@ University

- Need to enhance basic knowledge required for applied physics activities
- Need to recognize instrumentation activities as granting valuable PhD thesis

after University

- Strength the specialized training platforms in large lab/institutes

(EDIT school on Detectors: <https://indico.desy.de/indico/event/22513/>)

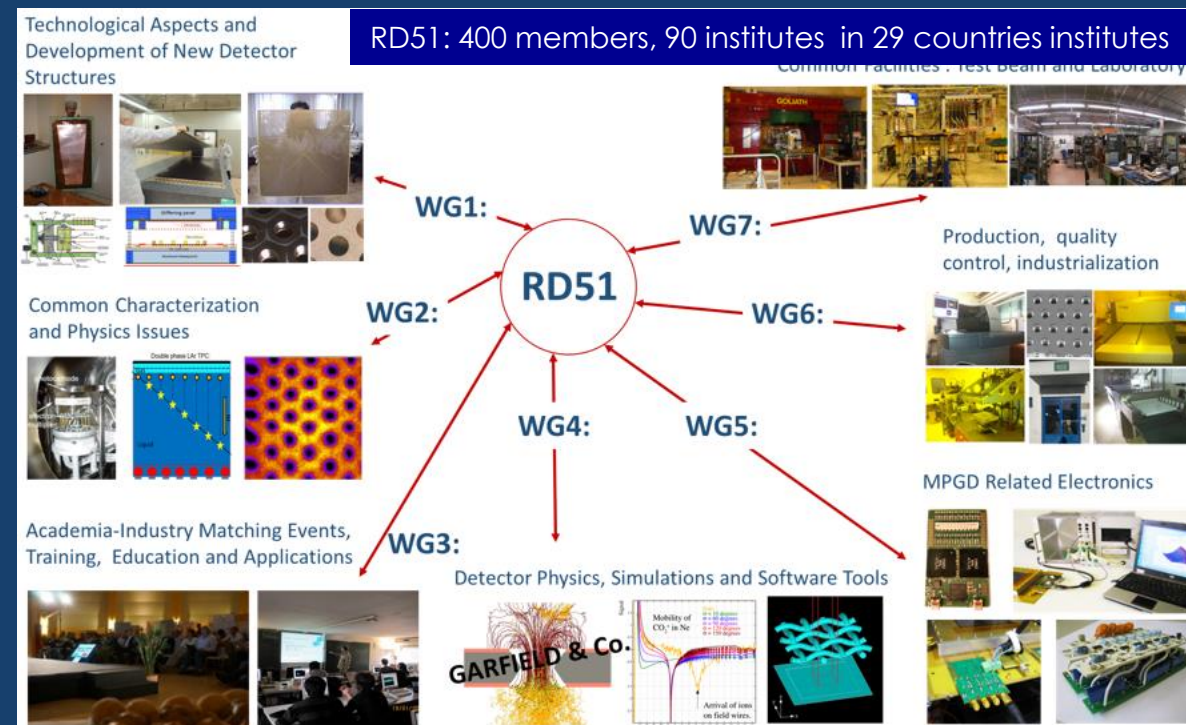
Granada take away messages

- There are many promising developments → Fast detectors, precise in time and space, ideally linked with energy determination, exploiting in-situ artificial intelligence → *The future is going towards multi-functional detectors !!!*
- Blue sky R&D can provide breakthrough technologies but it's a long process → *Need strong support*
- We can & it is necessary to bring fundamental research closer to the needs of the whole of society → *Review and strength our tech transfer model*
- In the μ -electronics realm → *Urgency for an international coordination & adequate resources for shared programs*
- R&D coordination → *Need to enhance collaboration and exchange of information between physics fields and technology specialisations*
- *Instrumentation activities need to be recognized as a fundamental research*
- *Career opportunities for detector physicists must be greatly strengthened*

BACKUP

example RD51 : μ pattern gaseous detectors

- Gather worldwide expertise in all aspects and provide visible framework for institutions
- Inherent large network for exchange of information
- Limit duplication and share work per areas
- Can include non HEP developments
- **Develop, provide access & distribute common tools \rightarrow Most effective framework to share resources with small institutes/users**
- Gives the possibility of common orders
- Define and adopt common test protocols, documentation, data bases
- Active environment for training and creating new expertise
- Provide door to industry relations



FTEs doing R&Ds in the major detectors categories

Detectors categories	% of FTEs
Vertex detectors	15
Trackers	23
Detectors for Particle Identification	14
Calorimetry	15
Timing detectors	12
Highly specialized instrumentation for Neutrino searches	7
Highly specialized instrumentation for Astroparticle	7
Other**	5

~40%

** gamma spectrometry, neutron detection, dosimeters, beam monitors, luminometers, gravitational waves.....

Photon detectors

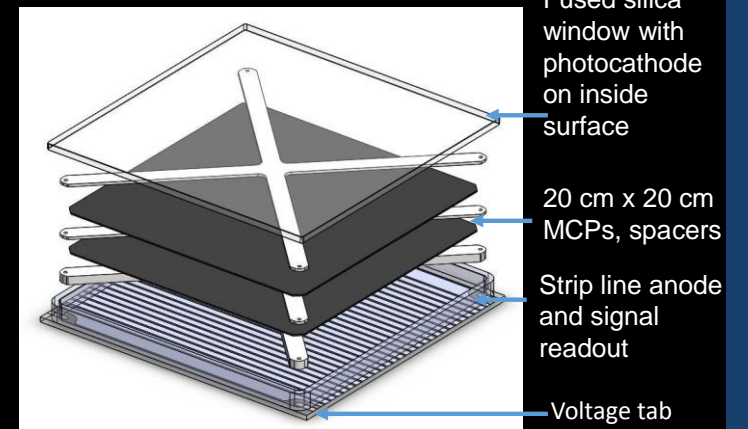
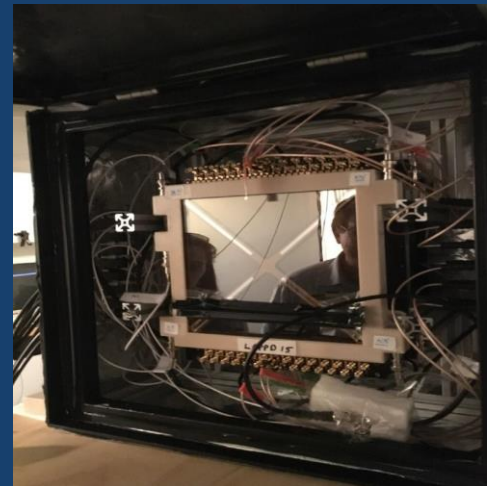
- Photon detection is key to many detection systems in HEP and in “invisible”
- **SiPM**, PMT, APD, **LAPPD**, Vacuum SiPM Tube
- Challenges:
 - Quantum efficiency $> 35\%$
 - Spectral response
 - Radiopurity
 - Speed
 - Noise



Large Area Picosec Photo Detectors

- Use Atomic Layer Deposition (ALD) Coating to Convert Glass Capillary Arrays into MCPs

LAPPD

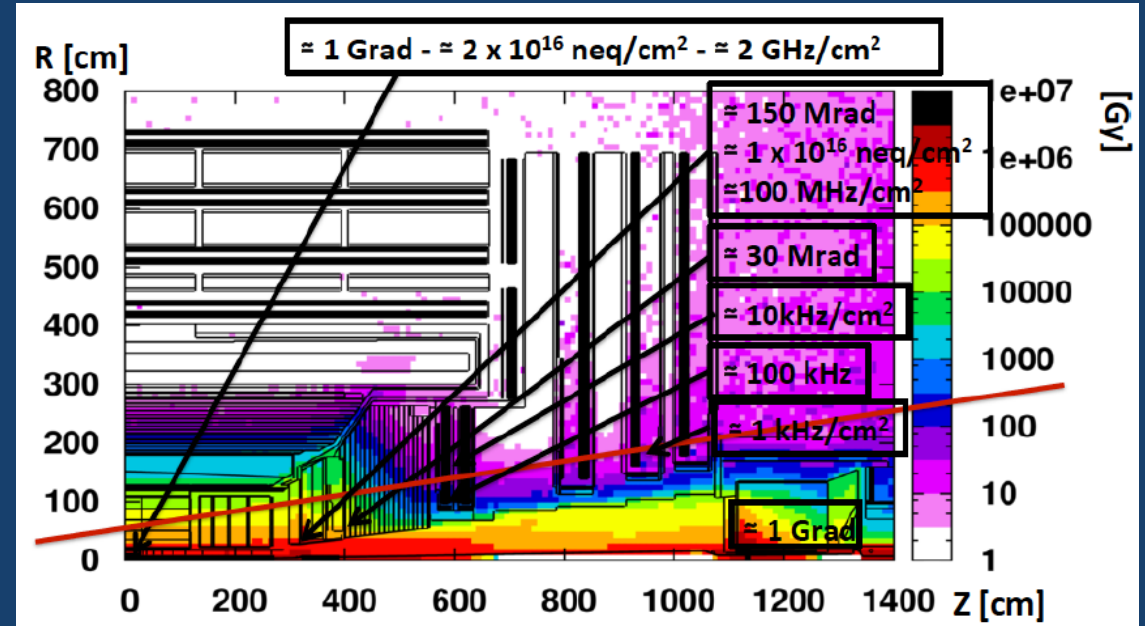


Micro Pattern Gas Detectors

- Very active field. Good coordination through RD51
- Future directions:
 - Resistive materials and architectures
 - Fast and precise timing
 - New materials and technologies
 - Hybrid detectors
- Challenges
 - Granularity
 - Time resolution
 - Large area, Large volume
- Reliability of industrial production still to be optimized for large surfaces
- Many applications, for instance treatment plans

Radiation

- Radiation resistance considerations are omni-present in detectors
- Huge progress in identifying materials and design techniques
- Next accelerators might increase the radiation level by more than a factor 10-100
 - FCC
 - Muon collider
- Solutions are not in hand today



1. Increasing radiation levels

- Semiconductor detectors will be exposed to hadron fluences equivalent to more than $10^{16} n_{eq}/cm^2$ (HL-LHC) and more than $7 \times 10^{17} n_{eq}/cm^2$ (FCC)
 - detectors used now at LHC cannot operate after such irradiation

2. New requirement and new detector technologies

- New requirements or opportunities lead to new technologies (e.g. HV-CMOS, LGAD,...) which need to be evaluated and optimized in terms of radiation hardness

G.Casse and M.Moll, RD50 Status Report,